

## PATENT SPECIFICATION

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(54) RARE EARTH PERMANENT MAGNET ROTOR FOR  
 DYNAMO ELECTRIC MACHINES AND METHOD OF  
 MANUFACTURING SAME

(71) We, KOLLMORGEN CORPORATION, of Radford, Virginia 24141, United States of America, a corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a rotor assembly for Dynamo Electric Machines comprising permanent magnetic material of extremely high energy product and intrinsic coercive force, exemplified by rare earth permanent magnet materials and hereinafter referred to as "Rare Earth Permanent Magnet Material".

The invention relates more particularly to a method of manufacturing a rotor for Dynamo Electric Machines of the "inside-out" type containing rare earth magnet material which is magnetized after assembly and machining of the rotor are completed and to rotors made by said method.

In a DC motor of the "inside-out" design the units-pole rotor is provided with permanent magnet members and the stator is provided with a number of poles whose windings are energized by the DC source. The ends of these windings are connected to an array of commutator bars. Commutation may be effected by means of rollers as shown in Patent Specification number 1 430 832 and US Patent Specifications No. 3 937 993 and 3 991 331, or conventional brush commutation techniques may be employed, for example a face plate or disc-type system as disclosed in Goraszko US Patent No. 3,275,861.

Traditionally, the permanent magnet members of DC motors of both conventional and "inside-out" designs have been alnico or ceramic Ferrite type magnet.

Following the advent of rare earth magnets, with their extremely high energy product and intrinsic coercive force, Rollin James Parker suggested in US Patent No. 3,836,802 that they be combined with alnico magnets in the stator of a conventional DC motor.

Magnets with very high energy products and intrinsic coercive force are very difficult to work with because of the extremely strong fields they create. Thus one of their greatest virtues is at the same time one of their greatest liabilities. It is simply not practical to machine rare earth magnets in the magnetized state at a structure containing such magnets because the machine particles adhere so strongly to the magnets.

Because of the extremely high coercive forces of rare earth magnets it is also not practical to construct a rotor or stator of rare earth magnets using known design concepts and then magnetize the structure as is commonly done with alnico magnets. Once again, the greatest virtues of rare earth magnet materials, i.e., extremely high resistance to demagnetization and extremely high achievable energy product in its magnetized state, is also one of the greatest liabilities.

Rare earth magnets are not presently available in the sizes of conventional magnets, i.e., they are typically furnished in the size of about 1/2" x 1/2" x 1" or smaller. When used with conventional magnets as part of a permanent magnet rotor assembly in a DC motor of the inside-out design they are glued to the rotor structure, a less than satisfactory mechanical bonding arrangement for high speed operation.

The present invention has for its object to overcome these disadvantages of rare earth magnets and to permit the efficient manufacture of rotor assemblies comprising such magnet materials.

We have overcome these and other difficulties associated with the use of rare earth magnets in DC motors and have provided a rotor containing rare earth magnet material, which rotor can be magnetized after assembly and machining is completed.

Rare earth magnet material in its unmagnetized state is hereinafter referred to as such material in its "virginal state".

According to the present invention a permanent magnet rotor for a DC motor of the "inside-out" type as hereinbefore defined comprises a plurality of pole pieces constructed of a plurality of laminations of ferrous material and having at least one set of openings; and pieces of rare earth permanent magnet material having a high energy product and intrinsic coercive force, and arranged in said openings, the said pole pieces having flux carrying cross sectional areas which are at least 1.5 times larger than required to carry the flux generated by said magnets in the magnetized state without saturation thus permitting *in situ* magnetization of said permanent magnet material if arranged in said pole piece openings in its "virginal state", as hereinbefore defined without limitation of magnetization by saturation of the material of said pole pieces.

In order to assure that the magnet material is in its unmagnetized state, hereinbefore referred to as virginal state, the said magnet material is preferably treated prior to assembly by heating it in the absence of iron which would complete the flux path of the magnet material, thus demagnetizing the magnet material to its (pseudo) "virginal" state.

For adjusting the field strength of the magnet material in the assembled rotor and after magnetizing, the rotor assembly may be heat treated in the absence or substantial absence of a return path for the magnet flux so that the magnet structure is exposed to the heat treatment in an air-stabilized condition and for a period of time sufficient to reduce magnetization to a desired and predetermined point, followed or not by remagnetization in the original direction to a second desired state of magnetization.

In another embodiment of the invention a permanent magnet rotor for a DC motor comprises a plurality of equally spaced laminated rotor pole pieces arranged to form a slot between each pair of adjacent pole pieces and further provided with openings and/or recesses; and a first set of pieces of permanent magnet material arranged to fill the said slots between pole pieces; and a second set of pieces of permanent magnet material arranged within said openings or in contact with the walls

of said recesses with each pole piece having flux carrying cross sectional areas which are at least 1.5 times larger than required to carry the flux generated by the respective permanent magnets in the magnetized state without saturation thus permitting *in situ* magnetization of said first set and said second set of pieces of magnet material without limitation of magnetization by saturation of the material of said pole pieces.

We have also developed a method of manufacturing a cast permanent magnet rotor for a DC motor of the inside out type as hereinbefore defined comprising the steps of assembling a stack of rotor lamination of ferrous material having first and second sets of openings; and inserting pieces of rare earth permanent magnet material having a high energy product and intrinsic coercive force in its magnetized state, but being in its virginal state as defined hereinbefore in said first set of openings in said laminations; and pouring non ferrous casting material into said second set of openings in said laminations so as to form a cast rotor assembly; and machining said cast rotor assembly to form a rotor assembly having discrete pole pieces said pole pieces having flux carrying cross-sectional areas which are at least 1.5 times larger than required to carry the flux generated by said permanent magnets in the magnetized state without saturation and mechanical dimensions with desired tolerances; and permanently magnetizing said pieces of magnet material *in situ* to thereby form a cast, permanent magnet rotor.

Rotors according to the present invention are suitable for use in DC machines of the type disclosed in co-pending specification 35320/75 Serial No. 1 487 877.

The invention will now be described more fully with reference to the drawings which show two embodiments and in which

Figure 1a is a top view of a rotor lamination; and

Figure 1b is a sectional view of a machined cast rotor employing the lamination of Figure 1a; and

Figure 2 is an end view of another embodiment of a permanent magnet rotor assembly; and

Figure 2a is a side view of the rotor of Figure 2.

In Figure 1a there is shown a rotor lamination 200 preferably of 1010-1020 steel and about 0.02 inches thick. Lamination 200 has a first set of equally spaced slots 201 adapted to receive pieces of rare earth magnet material. Lamination 200

also has a second set of equally spaced slots 202 adapted to receive molten material, preferably aluminium, during casting. Each of the first set of slots has lips or flanges adapted to retain the pieces of rare earth magnet material.

In manufacturing the rare earth magnet rotor of the present invention a stack of laminations 200 of desired size, for example 4 inches, is assembled. Next the pieces of rare earth magnet material are inserted into the slots 201 to build up a column the height of the stack of the laminations. The pieces of rare earth magnet material are typically 0.5 inches by 0.8 inches by 0.4 inches so that, in the present illustration, 10 pieces of rare earth magnet material would be required to fill each of the slots 201. The rare earth magnet material employed is preferably a cobalt-rare earth intermetallic compound, the preparation of such compounds and magnets therefrom being disclosed in Benz U.S. Patent Nos. 3,655,463, 3,655,464, 3,695,945 and Benz et al U.S. Patent No. 3,684,593. This rare earth magnet material must be in its virginal or pseudo-virginal state. It is permissible, however, if the rare earth magnet material possess weak magnetic fields due, for example, to the presence of the earth's magnetic field during formation of the rare earth magnet material.

Rather than assembling a complete stack of laminations followed by filling up the slots 201 with pieces of rare earth magnet material, the formation of the stack and insertion of the pieces of rare earth magnet material may proceed intermittently. The order is not critical and is merely a matter of choice.

After the laminations and pieces of rare earth magnet material have been assembled a shaft is preferably positioned at the center of the array, the axis of the shaft being coincident with the longitudinal axis of the stack of laminations. The shaft may be of a ferrous material such as steel.

The assembly of laminations, pieces of rare earth magnetic material and the rotor shaft is now ready for casting using a non-ferrous material, preferably aluminum because of its light weight. The molten aluminum flows into the second set of slots 202 thereby rendering rigid the rotor structure. It also locks the pieces of rare earth magnet material into the slots 201 and in the course of the casting operation has the effect of reducing any retained residual magnetism possessed by the rare earth magnet material by exposing it to heat. Finally, it integrates the rotor shaft into the assembly and makes it part of the rotor structure.

After casting the rotor is machined down so as to cut away those portions (201') of

the laminations radially aligned with the slots 201, thereby providing a plurality of separate pole pieces equally spaced around the rotor. Figure 1b shows in cross section the machined, cast rotor and having flux carrying cross-sectional areas which are at least 1.5 times larger than required to carry the flux generated by said permanent magnets in the magnetized state without saturation. The slots 201 are now filled with pieces of virgin rare earth magnet material 203 while the slots 202 are filled with aluminum 205 which also surrounds the rotor shaft 204.

The cast rotor with the virgin rare earth magnet material is now ready for magnetization. The rare earth magnet material used can be saturated with about 12,000 oersteds minimum and a field of 10,000 gauss. These low values may be employed because the rare earth magnet material is in virginal or pseudo-virginal state. In accordance with the present invention it was found out that the fact that the rare earth material is magnetized *in situ* in the cast rotor places certain constraints on the design of the rotor structure: the rotor pole pieces must be formed from laminations, otherwise the eddy current losses during magnetization would be too great; moreover, there must be sufficient iron available in the pole pieces to carry the flux into the rotor and saturate the pieces of rare earth magnet material during magnetization *in situ*. Thus, the rotor must contain more iron than necessary to carry the flux from the rare earth magnets during operation of the motor. The amount of iron required in the rotor to allow adequate magnetization *in situ* depends on the geometry of the pieces of rare earth magnet material. The longer the dimension of the rare earth magnet material in the radial direction, the more iron is required in the pole pieces. Accordingly, to ensure proper magnetization of the rare earth magnet material the rotor, flux-carrying cross-sections of the iron poles should have at least about 1.5 times the area necessary to carry the flux from the magnetized rare earth permanent magnets without saturation. When the dimension of the rare earth magnet material in the radial direction is large, the said cross-sectional pole area should be at least 2 to 3 times that necessary to carry the flux from the magnetized rare earth permanent magnets during operation of the motor.

Fig. 2 and 2a show another embodiment of the permanent magnet rotor of this invention for a DC motor. The permanent magnet rotor comprises a plurality of equally spaced, laminated rotor pole pieces 45, arranged in assemblies 44 to form a slot between each pair of adjacent pole

pieces 45, each having arcuate outer periphery and radially aligned sides 44b and 44c and further provided with an opening 44e. A first set of pieces of permanent magnet material is arranged to fill the said slots with rectangular-shaped permanent magnets 46. Rotor shaft 15 has a hexagonal shaped cross section extending the length of the permanent magnet assembly and is preferably formed of a magnetic material such as, for example, soft iron. A second set of elongated rectangular-shaped pieces of permanent magnet material 47 is arranged within the openings or recesses formed between pole pieces 45 and associated surfaces 15a of rotor shaft 15. The pole pieces 45 are dimensioned to have flux carrying cross-sectional areas which are at least 1.5 times larger than required to carry the flux generated by the respective permanent magnets in the magnetized state without saturation thus permitting in situ magnetization of said first set and said second set of pieces of permanent magnet material without limitation of magnetization by saturation of the material of said pole pieces.

The magnets 46 are of material having an extremely high energy product and intrinsic coercive force (rare earth magnets) which resist demagnetization, provide better impedance matching and serve to increase flux density across the air gap. Magnets 47 are preferably Alnico-8 magnets. The arrangement of magnet members 46, 47 and 46 embrace pole pieces 45 and serves to concentrate the flux density in the air gap.

Figure 2a shows the manner of assembly of the rotor permanent magnet structure. End caps 49 and 50, rods 51 and fastening nuts 52 hold the permanent magnet assembly together. Set screws 53 and 54 engage tapped openings in collar portions 49a and 50a of the end caps 49 and 50 to lock the assembly to shaft 15.

#### WHAT WE CLAIM IS:—

1. A permanent magnet rotor for a DC motor of the "inside-out" type as hereinbefore defined comprising a plurality of pole pieces constructed of a plurality of laminations of ferrous material and having at least one set of openings; and pieces of rare earth permanent magnet material having a high energy product and intrinsic coercive force and arranged in said openings, the said pole pieces having flux carrying cross-sectional areas which are at least 1.5 times larger than required to carry the flux generated by said permanent magnets in the magnetized state without saturation thus permitting in situ magnetization of said permanent magnet material if arranged in said pole piece openings in its "virginal state" as hereinbefore defined

without limitation of magnetization by saturation of the material of said pole pieces.

2. A magnet rotor according to Claim 1 wherein the said cross-sectional areas of said pole pieces are between two and three times larger than required to carry the flux generated by said permanent magnets in the magnetized state.

3. A permanent magnet rotor as claimed in Claim 1 wherein said cross sectional areas are dimensioned to permit magnetization of said magnet material in its "virginal state" with at least 12 000 oersteds to develop a field of at least 10 000 gauss.

4. A method of manufacturing a cast permanent magnet rotor for a DC motor of the "inside-out" type as hereinbefore defined comprising the steps of:

(a) assembling a stack of rotor laminations of ferrous material having first and second sets of openings; and

(b) inserting pieces of rare earth permanent magnet material having a high energy product and intrinsic coercive force in its magnetized state but being in its "virginal" state as defined hereinbefore in said first set of openings in said laminations; and

(c) pouring non-ferrous casting material into said second set of openings in said laminations so as to form a cast rotor assembly; and

(d) machining said cast rotor assembly to form a rotor assembly having discrete pole pieces said pole pieces having flux carrying cross-sectional areas which are at least 1.5 times larger than required to carry the flux generated by said permanent magnets in the magnetized state without saturation and mechanical dimensions with desired tolerances; and

(e) permanently magnetizing said pieces of magnet material *in situ* to thereby form a cast, permanent magnet rotor.

5. The method of Claim 4 comprising the additional step of positioning a rotor shaft coincident with the longitudinal axis of said stack of rotor laminations prior to the step of pouring said casting material.

6. The method according to Claim 4 comprising the additional step of adjusting the field strength of said rare earth permanent magnets by heating said cast, rare earth permanent magnet rotor assembly in a heating arrangement which is substantially free of magnetically conductive material so that the magnet structure is exposed to the heat treatment in an air-stabilized condition and for a period of time sufficient to reduce magnetization to a desired and predetermined point, followed or not by remagnetization in the original direction to a second desired state of mag-

netization.

7. A permanent magnet rotor for a DC motor comprising a plurality of equally spaced laminated rotor pole pieces arranged to form a slot between each pair of adjacent pole pieces and further provided with openings and/or recesses; and a first set of pieces of permanent magnet material arranged to fill the said slots between pole pieces; and a second set of pieces of permanent magnet material arranged within said openings or in contact with the walls of said recesses with each pole piece having flux carrying cross-sectional areas which are at least 1.5 times larger than required to carry the flux generated by the respective permanent

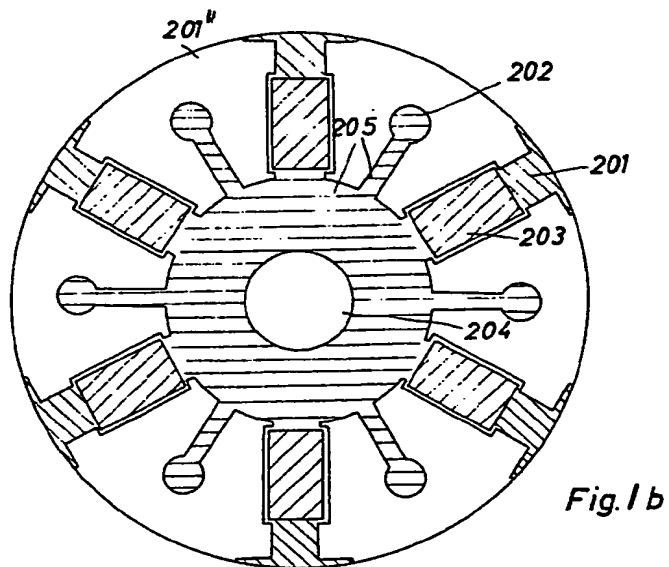
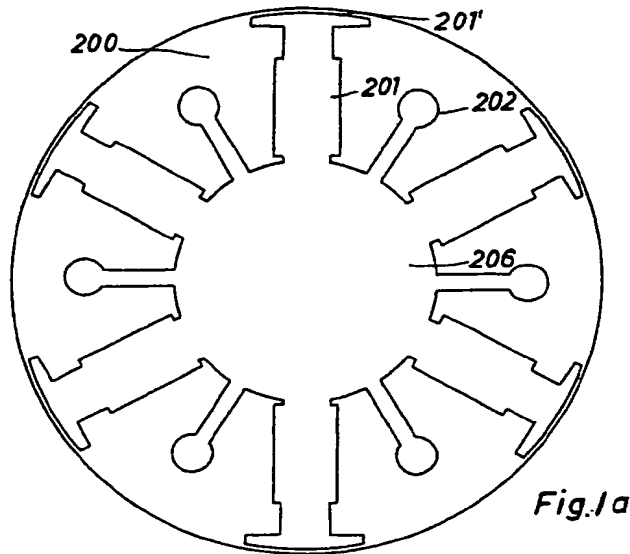
magnets in the magnetized state without saturation thus permitting in situ magnetization of said first set and said second set of pieces of permanent magnet material without limitation of magnetization by saturation of the material of said pole pieces.

8. The method as claimed in one or more of Claims 4 to 6 wherein said step of magnetizing the magnet material comprises saturating said pieces of magnet material with at least about 12,000 oersteds and a field of 10,000 gauss.

9. The method as claimed in at least one of Claims 4 to 6 wherein said casting material comprises molten aluminum.

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COMPLETE SPECIFICATION

2 SHEETS

This drawing is a reproduction of  
the Original on a reduced scale

Sheet 2

